

Delineating stations along the coastline of Delta State, Nigeria into pollution categories: multivariate approach

ABSTRACT

Disturbance of aquatic systems have been of major concern to their health. The disturbances experienced by the systems arise mainly from human influences. In this present study, we delineated six stations into pollution categories using multivariate approach (principal component analysis; PCA); namely; SW 1- sea water (Benin River mouth/sea), SW2- Benin River (Benin River mouth/sea), SW3- sea water (Escravos River mouth/sea), SW4-River mouth (Escravos River mouth/sea), SW5- sea water (Forcados River mouth/sea) and SW6-River mouth (Forcados River mouth/sea). The PCA we constructed to visualize the correlation between the sampled stations and selected physico-chemical parameters showed that components 1 had a variance of 53.29% with an eigenvalue of 6.93 while component 2 explained 38.10% with an eigen value of 4.95. SW1 and SW2 were negatively correlated with DO, THC and conductivity, and nitrate, COD, TSS and temperature were negatively correlated with SW5 and SW6. Phosphate, salinity and turbidity were positively correlated with SW3 and SW4, and sulphate, pH and BOD had no correlation with any of the stations. Of the six stations we delineated, four were categorized as heavily polluted and they include; SW1, SW2, SW5 and SW6, while SW3 was moderately polluted and SW4 was fairly polluted. This showed the Delta State of Nigeria coastlines are heavily impacted by human influences.

Keywords: Station delineation, pollution categories, Delta State coastline, Nigeria

1. INTRODUCTION

Urbanisation and industrial developments have been implicated in aggravating the level of pollution in aquatic systems [1-2]. In the present study area, Delta State within the Niger Delta region of Nigeria, industrial developments are on the rise due to the presence of crude oil deposition in most part of the state. Hence, activities resulting from the exploration of the crude oil have resulted in the degradation of the environment and aquatic systems are the most affected.

In assessing, the levels of degradation in aquatic systems, the concentrations of physico-chemical parameters have been employed. For instance high concentrations of parameters such as nutrients (sulphate, nitrate and phosphate), biochemical oxygen demand (BOD), conductivity and turbidity have been used as measures to conclude that a system is impacted by human influences [3-4]. Following the thinking of previous studies, we analyse selected physico-chemical parameters in the current study in a bid to assess the level of degradation the stations we marked are subjected.

Aside the use of descriptive statistics to ascertain the level of significance as well as the debilitating effects various level of concentrations of the physico-chemical parameters had on the environment, multivariate approaches such as non-metric multidimensional scaling (NMDS), principal component analysis (PCA) and canonical analysis of principal coordinates (CAP) [5-7]. Among these multivariate approaches employed in identifying and classifying stations into impact categories, the PCA is one of the most employed approaches. The PCA is an ordination analysis used to explain the correlation between environmental parameters and stations [8]. The PCA is a biplot that help in relating stations with environmental variables as well delineate the stations into level of pollution. Other studies have also employed the PCA in classifying sites into impact categories. For instance, Edegbene et al. [7] recently classified 20 stations in 11 riverine systems into pollution impact categories namely: least impacted sites (LIS), moderately impacted sites (MIS) and heavily impacted sites (HIS). Also, Ogidiaka et al. [6] classified five sites in Forcados estuary into three potential ecological classes along a pollution gradient

namely; least disturbed stations (LDS), moderately disturbed stations (MDS) and heavily disturbed stations (HDS). Following the thinking of these authors, we delineated six stations in the current study area into pollution categories in a bid to using them as ecological meter to assess the level of degradation aquatic stations are subjected in the Niger Delta region of Nigeria. Therefore, the current is aimed at delineating stations along the coastline of Delta State, Nigeria into pollution categories using multivariate approach.

2. MATERIAL AND METHODS

2.1 The Study Area

The study area is located along the coastline of Delta State within the Niger Delta region of Nigeria. The Niger Delta region occupies an approximate area of 70, 000 km² and it is located at the southern tip of Nigeria [9]. The region is said to be the third largest wetland system in the world [10-11]. The area is characterised by mangrove swamps, wetlands, inland waters, brackish waters, vegetation, and an extensive tropical rain forest [12-13]. Two seasons characterised the study area: wet and dry seasons, the wet season is between March and October, and the dry season is between November and February. Three riverine systems namely: Benin, Escravos and Forcados Rivers and two stations each were marked out per system. Table 1 below shows the six stations sampled, their geographical location based on geographical positioning system (GPS), features of the station reaches, community and activities along each stations.

Table 1: The coastline and sand beaches, geographical locations, features, communities and activities of the sampling sites of the three riverine systems sampled in the present study area

Stations	Coastline and sand beaches	GPS Location	features	Community	Activities
SW1	Seawater	4.954592, 5.823057	5km into the Atlantic	Ogheye	Maritime
SW2	Benin River	5.072377, 5.757282	500m Benin River	Orere	Local fishing
SW3	Seawater	5.05861, 5.622671	5km into the Atlantic	Aruton	Oil and gas platforms
SW4	Escravos River	5.174864, 5.573722	500m Escravos River	Ogidigben	Chevron Terminal
SW5	Seawater	5.151919, 5.440641	5km into the Atlantic	Forcados	Oil and gas logistics
SW6	Forcados River	5.311005, 5.385573	500m Forcados River	Beniboye/Ogulagha	Shell Terminal

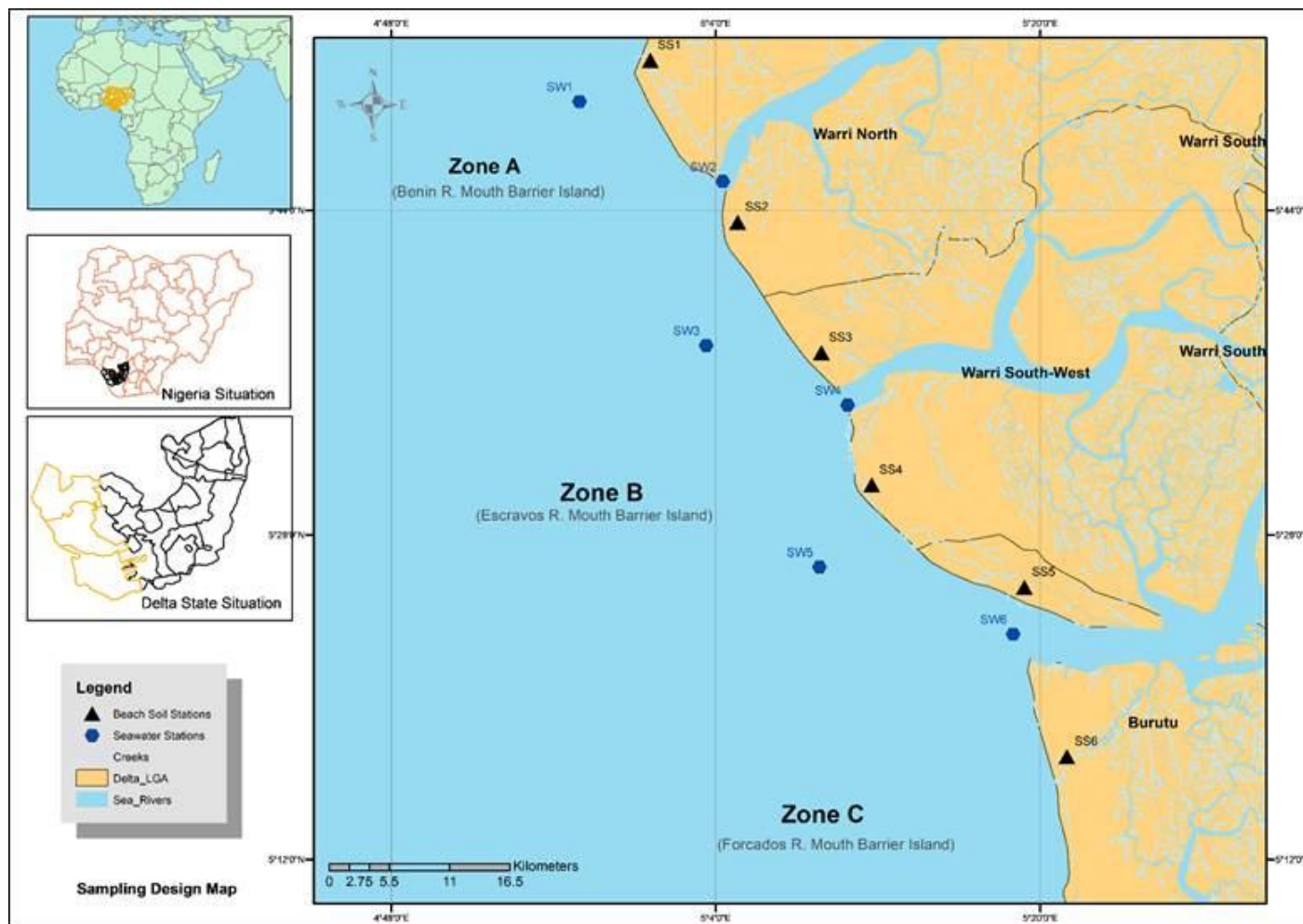


Figure 1: Map of the study area showing the sampling sites along the coastline and the barrier ridges (coastal sand) of Delta State, Nigeria

Sampling and analysis of *Physico-chemical parameters*

The surface water physico-chemical parameters were collected and analysed for a period of 22 months spanning between November 2019 and August 2021. The following physico-chemical parameters were analyzed in the course of the present study: pH, temperature, conductivity, salinity, dissolved oxygen (DO), turbidity, total suspended solids (TSS), total hydrocarbon (THC), biological demand oxygen (BOD), chemical oxygen demand (COD), nitrate, sulphate and phosphate. pH was measured using pH meter (model: HANNA HI 9828), temperature was measured using mercury-in-glass thermometer in °C. Conductivity and TSS were measured using conductivity meter (model: DDSJ-308A). Turbidity was measured using turbidity meter (model: WGZ-B) and it was measured in nephelometric turbidity unit (NTU). THC, BOD, COD, nitrate and phosphate were determined following APHA [14] methods.

Data analysis

Mean, standard error and range of physicochemical variables were calculated per station using the Univariate function on Palaentological Statistical package (PAST) [15]. Two-Way Analysis of Variance (ANOVA) without replicate was used to test for differences ($P < 0.05$) in the means of the measured water physico-chemical parameters between the six sites sampled [6]. When ANOVA indicated significant differences, a post-hoc test, the Tukey's Honest Significant Different (HSD) test was computed to indicate station mean that showed significant difference.

We used principal component analysis (PCA) to correlate selected physico-chemical parameters with the six sampled stations. Station pollution category was undertaken by first extricating the coordinate's score loadings from the first component of the PCA. The first component of the PCA was used because it

explained the highest variance (53.29%) among the six PCA components visualized. The PCA was constructed using PAST [15].

We categorized the six stations into pollution categories by following the thinking of Edegbene [4] who used the first axis of PCA to delineate sites into gradient of pollution, following: (i) the coordinate scores of the six stations were extricated, (ii) the extricated scores were used to calculate inter-station distance of each station by subtracting the lowest scoring station from the remaining stations one after the other, (iii) we converted the inter-station distance to percentages, and (iv) we used three particle distribution to delineate the stations into pollution categories; 100% (fairly polluted, FP), 50%-99.99% (moderately polluted, MP), 0-<50% (heavily polluted; HP). The PCA was constructed using PAST [15].

3. RESULTS AND DISCUSSION

3.1 RESULTS

The mean, standard error, minimum and maximum values, ANOVA (F-values, p-values) of the physico-chemical parameters in the stations sampled along the coastline of Delta State, Nigeria as well as the Turkey Honest significant differences (HSD) among stations means are summarized in Table 2.

The highest mean dissolved oxygen (DO) (6.57 ± 0.028) was recorded in SW1, and the highest conductivity (425.09 ± 8.69) and total hydrocarbon (THC) (0.84 ± 0.038) were recorded in SW2 (Table 2). pH (7.39 ± 0.046), salinity (21.59 ± 0.89), sulphate (1.67 ± 0.066) and phosphate (0.26 ± 0.02) highest mean values were recorded in SW3 (Table 2). Turbidity (6.26 ± 0.41) was highest in SW4, and biochemical oxygen demand (BOD) (2.89 ± 0.38) were highest in SW5 (Table 2). Total suspended solids (TSS) (24.01 ± 1.66), temperature (31.20 ± 0.66), chemical oxygen demand (COD) (6.86 ± 0.50) and nitrate (2.11 ± 0.44) were highest in SW6 (Table 2). pH, temperature, conductivity, turbidity, chemical oxygen demand, nitrate, sulphate and phosphate were significantly different in both the stations and months sampled ($P < 0.05$). Salinity, dissolved oxygen, total hydrocarbon and biochemical oxygen demand were only significantly different among the stations sampled ($P < 0.05$), while salinity, DO, total suspended solids, THC and BOD were not significantly different among the months sampled ($P > 0.05$).

Table 2: Summary of physico-chemical parameters of the stations sampled along the coastline of Delta State, Nigeria

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	Months		Stations	
							F-value	P-value	F-value	P-value
pH	7.39±0.046 (7.07-7.72) ^{abd}	7.27±0.033 (7.1- 7.61) ^{abd}	7.92±0.083 (7.19- 7.61) ^{bc}	7.67±0.065 (7.06- 8.1) ^{cd}	7.77±0.098 (5.98- 8.32) ^{cd}	7.83±0.054 (6.88- 8.14) ^{cd}	2.60	0.00076	18.86	2.42E-13
Temperature (°C)	28.29±0.15 (27.0- 30.0) ^{abc}	28.52±0.24 (25.3- 29.9) ^{abc}	27.22±0.39 (20.9- 29.98) ^{abc}	8.16±0.11 (27.48- 29.05) ^{bc}	30.0±0.70 (25.3- 38.6) ^{bc}	31.20±0.66 (26.9- 37.4) ^c	2.76	0.00035	13.71	2.69E-10
Conductivity (µS/cm)	391.77±10.1 (320- 469) ^{abc}	425.09±8.69 (321- 473) ^{bc}	34.23±1.28 (13.4- 39.0) ^c	35.49±1.00 (16.8- 39.4) ^c	28.11±1.42 (18.4- 39.2) ^c	28.11±1.42 (18.4- 39.2) ^c	1.53	0.083	1350.71	1.48E-93
Salinity (g/L)	14.24±0.85 (10.0- 23.13) ^{ab}	14.46±1.057 (8.1- 23) ^{ab}	21.59±0.89 (7.7- 29) ^b	2.27±1.12 (10.0- 31.8) ^b	14.16±1.33 (2.85- 23.4) ^a	14.58±1.44 (2.88- 27.1) ^a	0.49	0.97	11.05	1.46E-08
DO (mg/L)	6.57±0.028 (6.40- 6.80) ^{abc}	6.55±0.030 (6.30- 6.78) ^{abc}	3.97±0.15 (2.99- 5.20) ^{bc}	3.87±0.11 (3.00- 5.00) ^{bc}	3.48±0.11 (2.68- 4.30) ^c	3.59±0.16 (2.90- 6.30) ^{bc}	0.58	0.92	165.86	3.62E-48
Turbidity (NTU)	4.29±0.41 (1.60- 8.18) ^{ac}	5.32±0.49 (1.65- 8.50) ^{abc}	5.46±0.47 (1.69- 8.00) ^{ac}	6.26±0.41 (2.40- 9.00) ^c	5.48±0.35 (3.15- 8.20) ^{ac}	4.02±0.26 (2.70- 7.90) ^{ac}	7.31	1.07E-12	8.66	6.74E-07
TSS (mg/L)	15.45±1.67 (4.97- 31.0) ^{abc}	15.07±1.97 (4.96- 31.4) ^{abc}	13.30±1.67 (4.00- 42.00) ^{bc}	12.70±0.54 (6.10- 20.0) ^{ab}	22.91±3.89 (10.50- 70.00) ^{ac}	24.01±1.66 (10.50- 35.00) ^c	0.91	0.57	5.39	0.000109
THC (mg/L)	0.82±0.039 (0.49- 1.20) ^{ab}	0.84±0.038 (0.45- 1.30) ^{ab}	0.28±0.023 (0.10- 0.61) ^b	0.29±0.013 (0.17- 0.43) ^b	0.28±0.017 (0.12- 0.49) ^b	0.28±0.017 (0.12- 0.43) ^b	1.24	0.23	118.66	1.47E-41
BOD (mg/L)	1.10±0.20 (0.11- 2.80) ^a	1.42±0.18 (0.40- 3.50) ^a	1.63±0.13 (0.56- 2.60) ^{abc}	2.57±0.25 (1.02- 5.69) ^b	2.89±0.38 (1.02- 6.50) ^{abc}	2.64±0.38 (0.80- 6.54) ^{ab}	1.036	0.43	7.59	4.03E-06
COD (mg/L)	2.35±0.30 (1.01- 5.15) ^a	4.04±0.32 (1.02- 6.8) ^{ab}	3.23±0.38 (1.00- 5.90) ^{ab}	3.00±0.34 (1.02- 5.80) ^{ab}	4.46±0.69 (0.40- 10.00) ^{bc}	6.86±0.50 (1.14- 10.00) ^c	0.70	0.82	12.23	2.37E-09
Nitrate (mg/L)	0.15±0.037 (0.06- 0.9) ^{ab}	0.087±0.01 (0.02- 0.17) ^{ab}	0.088±0.06 (0.02- 0.12) ^{ab}	0.11±0.03 (0.02- 0.7) ^{ab}	1.91±0.39 (0.08- 5.0) ^b	2.11±0.44 (0.04- 5.5) ^b	2.62	0.00069	20.96	1.77E14
Sulphate (mg/L)	0.25±0.006 (0.20- 0.30) ^{ab}	0.24±0.0056 (0.21- 0.29) ^{ab}	1.67±0.066 (0.59- 2.00) ^b	1.58±0.059 (0.77- 2.00) ^{bc}	1.25±0.12 (0.08- 2.00) ^{bc}	1.33±0.12 (0.06- 2.00) ^b	1.56	0.074	70.61	5.24E-32
Phosphate	0.23±0.034	0.25±0.029	0.26±0.02	0.29±0.025	0.19±0.048	0.14±0.021	1.52	0.085	3.075	0.012

(mg/L) (0.09-0.86)^a (0.04-0.49)^a (0.02-0.4)^a (0.02-0.44)^a (0.008-1.01)^a (0.01-0.31)^{ab}

Note: Values are mean±SE; (minimum values-maximum values) in parenthesis. Different superscript letters in a row show significant differences ($p < 0.05$) indicated by Tukey Honest Significant Difference (HSD) tests. SW abbreviations: SW 1- sea water (Benin River mouth/sea), SW2- Benin River (Benin River mouth/sea), SW3- sea water (Escravos River mouth/sea), SW4-River mouth (Escravos River mouth/sea), SW5- sea water (Forcados River mouth/sea) and SW6-River mouth (Forcados River mouth/sea)

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The PCA we constructed to visualize the correlation between the sampled stations and selected physico-chemical parameters showed that components 1 had a variance of 53.29% with an eigenvalue of 6.93 while component 2 explained 38.10% with an eigen value of 4.95 (Figure 2).

SW1 and SW2 were negatively correlated with DO, THC and conductivity, and nitrate, COD, TSS and temperature were negatively correlated with SW5 and SW6 (Figure 2). Phosphate, salinity and turbidity were positively correlated with SW3 and SW4, and sulphate, pH and BOD had no correlation with any of the stations (Figure 2).

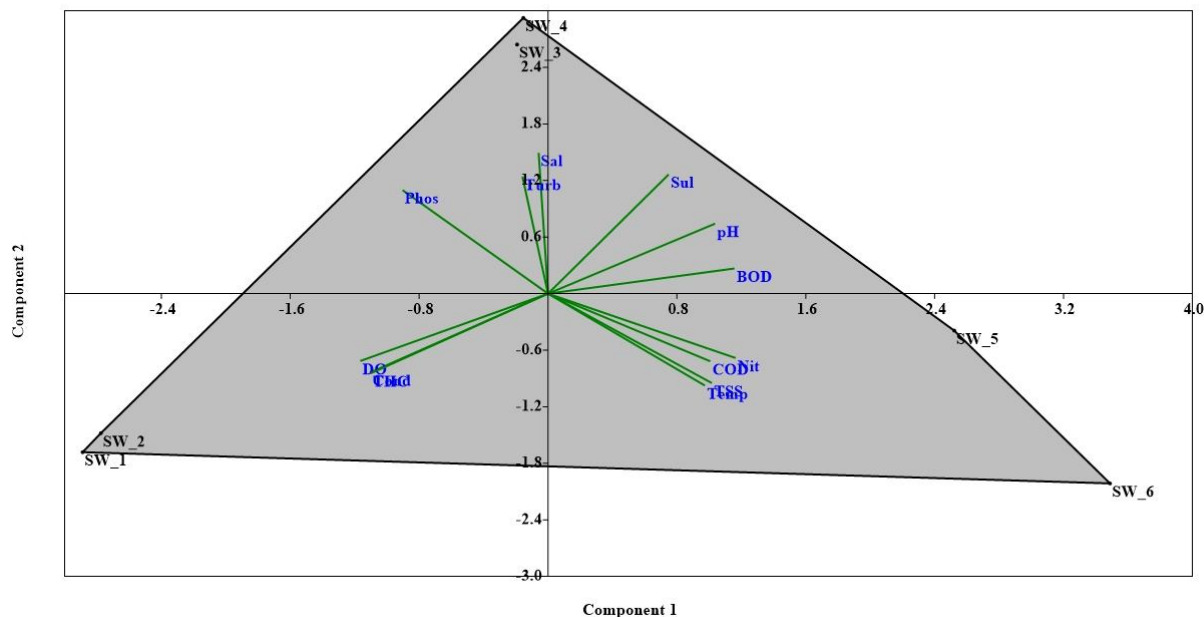


Figure 2: Principal component analysis (PCA) based on correlation matrix showing the correlation between selected physico-chemical parameters and stations sampled along the coastline of Delta State, Nigeria
Physico-chemical variables abbreviations: Temp = temperature, Cond = conductivity, Sal = salinity, DO = dissolved oxygen, Turb = turbidity, TSS= total suspended solids, THC =total hydrocarbon, BOD = biochemical oxygen demand, COD = chemical oxygen demand, Nit =nitrate, Sul= sulphate, Phos =phosphate.

Based on the visualization from the PCA, we further delineated the six stations into pollution categories, and four out of the six stations were categorized as heavily polluted and they include; SW1, SW2, SW5 and SW6, while SW3 was moderately polluted and SW4 was fairly polluted (Table 3).

Table 3: Categorizing selected stations along the coastline of Delta State, Nigeria

Stations	Extracted coordinates from PCA component 1	Inter-station distance	Inter-station distance (%)	Pollution category
SW1	-2.889	0.00	0.00	heavily polluted (HP)
SW2	-2.7755	0.1135	4.12	heavily polluted (HP)
SW3	-0.192	2.697	98.59	moderately polluted (MP)
SW4	-0.15331	2.73569	100	fairly polluted (FP)
SW5	2.5215	-0.3675	-13.43	heavily polluted (HP)
SW6	3.4883	0.5993	21.9	heavily polluted (HP)

3.2 DISCUSSION

We delineated selected stations into pollution categories along the coastline of Delta State, Nigeria using multivariate approach in the current study. Results of the analyses of physico-chemical parameters showed an environment typical of afrotropical aquatic systems. For instance, the pH along the six stations showed an alkaline nature of the water. This is as expected as most of the sites are within the marine ecosystem. The salinity concentration further buttress the salty water nature of the study area, as mean salinity was as high as 14.24 ± 0.85 g/L, 14.46 ± 1.44 g/L, 21.59 ± 0.89 g/L, 14.16 ± 1.33 g/L and 14.58 ± 1.44 g/L were recorded in SW, SW2, SW3, SW5 and SW6, respectively (Table 2). Similarly, findings with regards to alkaline pH and relatively saline water had earlier been reported [16-17] in the studies they conducted in salt water bodies in the Niger Delta region of Nigeria. Most recently, Ogidiaka [6] reported a relatively alkaline water system in their study at the Forcados Estuary, Delta State. Furthermore, most of the parameters showed a degrading ecosystem sites judging from the high values of some physico-chemical parameters indicating pollution gradient recorded. High concentrations of conductivity, BOD and nutrients were recorded in most of the stations. Similar studies had reported concomitant high concentrations of pollution indicating [e.g. 5, 17]. These they attributed to increasing urban development, industrialization and agricultural activities. In the current study area, urban settlements and oil exploration firms dominate most of the stations we sampled. This might probably be the reason high concentrations of some physico-chemical parameters were recorded in most of the stations.

In delineating the stations into pollution categories, we constructed a PCA, and the PCA first two axes accounted for 91.39% of the total variance of the entire PCA variance, and this showed a good ordination [5-18]. Other studies had showed that a PCA variance of 70%-90% are considered good enough to decide the reliability of environmental variables used in constructing ordination plots [18]. On the PCA ordination we constructed, parameters such as turbidity, COD, nitrate and conductivity correlated with SW5 and SW6. This showed the level of degradation these stations have been subjected. Further, analysis we performed classified SW5, SW6, and SW1 and SW2 as heavily impacted stations. On the other hand, SW3 and SW4 were classified as moderately and fairly polluted, respectively. This result revealed that most of the stations in the systems sampled are subjected to high level of anthropogenic influences. This is expected owing to the growing urban settlements as well as industrial developments (e.g. the presence of oil exploration outlets in most reaches of the aquatic systems) within the Niger Delta area of Nigeria.

4. CONCLUSION

This current study, present a baseline information on the health of the Delta State of Nigeria coastline. Key physico-chemical parameters were used to delineate stations into pollution categories using multivariate approach (PCA). Pollution indicating physico-chemical parameters such as THC, conductivity, and nitrate, COD and TSS and temperature correlated with SW1 and SW2. Further analysis showed the SW1 and SW2 were heavily polluted, confirming the level of deterioration the Delta State of Nigeria coastline are subject to.

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